COPY NO. 27

TECHNICAL REPORT 4119

AN ELECTROSTATIC SPARK SENSITIVITY TEST OF COMPOSITION B

ROBERT F. GENTNER

DECEMBER 1970

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

PICATINNY ARSENAL
DOVER, NEW JERSEY

35

Technical Report 4119

AN ELECTROSTATIC SPARK SENSITIVITY TEST OF COMPOSITION B

by

Robert F. Gentner

December 1970

Approved for public release; distribution unlimited.

AMCMS CODE: 4810.16.2929.6

Explosives Laboratory
Feltman Research Laboratories
Picatinny Arsenal
Dover, New Jersey

TABLE OF CONTENTS

	Page
Abstract	1
Introduction	2
Experimental Details	2
Results	4
Capacitor Discharge	4
Energy Considerations	6
Explosive Test Data	7
Discussion	8
Simulation	8
Test Item	10
Multiple Tests	10
Conclusions	11
Further Work	11
Acknowledgment	13
References	13
Appendix Mathematical Model of the Discharge Circuit	24
Tables	
1 Explosive test data	14
2 Calculated energy dissipation and time to maximum current as functions of control resistor	15

Page

Figures

1	Detonator/squib assembly	15
2	Circuits used	17
3	Voltage across spark gap during discharge	18
4	Voltage across spark gap and resistor during discharge	19
5	Voltage across resistor during discharge	20
6	Voltage across krytron and spark gap during discharge	21
7	Typical voltage traces for a Comp B loaded item	22
8	Current-voltage characteristics of a spark gap	23
9	Schematic of discharge circuit	23

Distribution List 29

ABSTRACT

This report describes an investigation related to the possibility that an accidental electrostatic discharge within a munition may initiate a Composition B main charge. The source, in the supposed mechanism, is a 1500-picofarad capacitor charged to a maximum of 3000 volts (67,500 ergs). The fraction of this energy available to the explosive, as a function of time depends on the circuit parameters and the arc characteristics. The test device used to simulate the discharge stress applied to the explosive employed a 0.05-microfarad capacitor charged to 3400 volts. Approximately 10% (300,000 ergs) of the stored energy appears in the spark gap with about a 0.2-microsecond time constant for the discharge. Repeated application of this discharge to the surface of the explosive did not initiate the Composition B. A method for measuring the energy in the spark gap is described. A mathematical model of the discharge circuit is developed and its predictions are compared with the experimental results. The potential of the test device for measuring the electrostatic sensitivity of explosives is discussed.

INTRODUCTION

This investigation was undertaken in response to a request by the Ammunition Engineering Directorate to examine the possibility that a particular electrostatic discharge could initiate Composition B under conditions simulating an improbable event within an XM409 shell. The event would follow several switching malfunctions as well as deficiencies in quality control in the production of the particular shell involved. During launch, these malfunctions and deficiencies would lead to a piezoelectric source discharging across a gap in a defective wire or from it through damaged insulation to a metal surface. The most severe conditions which might occur were to be represented by a 1500-picofarad capacitor charged to 3000 volts discharging across a few-hundredths-inch-long gap between concentric electrodes which were in contact with cast (or crushed) Composition B. The effects of setback pressures were also to be considered.

This report describes the experimental apparatus and procedure used in the study. A technique for determining the amount of energy dissipated in the spark gap and other circuit elements is given. The results and discussion follow with suggestions for further work. Finally, in the Appendix, a model for the discharge of the capacitor through the spark gap is described and results obtained with it are compared with the experimental results.

EXPERIMENTAL DETAILS

The test item (see Fig 1) was assembled as follows: A weighed quantity of explosive was placed in an M94 cup which was held in loading tools modified from the standard ones used with the M55 detonator. Next, a coaxial electrode squib was placed on top of the explosive and subjected to the desired pressure. (The ram was constructed so that it contacted the squib only on its outer ring.) Finally, the detonator cup was crimped, first at 45° and then flat. The effect was to have an annular gap of 0.030 inch across glass insulation in intimate contact with the surface of the explosive. This is intended to simulate discharge conditions across a short gap that might exist in the munition. To obtain statistically reliable results, a very large number of tests are required. However, it was not practical to carry out such large numbers of tests using single items. Therefore, in an effort to gather sufficient data (for statistically meaningful results) in a reasonable length of time, multiple discharges were applied to single items. The merits of this approach are treated in the DISCUSSION section of this report.

The simulation of the discharge within the munition proposed the delivery of 0.00675 joule (from a 1500-picofarad capacitor charged to 3000 volts) to the vicinity of the explosive for an unspecified period of time. In practice, the amount of energy actually transferred from the capacitor depends on both the resistance and the sustaining voltage of the spark discharge as well as on the circuit parameters. The resistance of a spark in air has been estimated (Ref 1) to be about 0.1 ohm. If one adds to this an assumed munition circuit resistance to give a total of one ohm, the relaxation time would be only 1.5 nanoseconds. For such short pulses, it was not possible with the equipment available either to make measurements of energy at the explosive or to provide a sufficiently low resistance switching circuit for multiple discharges. Therefore, modifications were made in the simulation; the discharge circuit adopted is shown in Figure 2. It uses a larger (0.05 microfarad) capacitor and a resistor in series with the arc. It permits measurements of the energy distribution with time. The relation of the results obtained with this equipment to the results for a 0.00675 joule 1.5 nanosecond pulse is treated in the DISCUSSION section.

High voltage is furnished from a variable 0-5 kilovolts power source obtained from Precise Measurements Corporation. A KN22 Krytron (E G & G), which is a four-element cold-cathode gas-filled switch tube operating in an arc discharge mode, is used to transfer the voltage to the test item. This tube dissipates a considerable fraction of the energy, as the APPENDIX shows. It operates in the 500-5000 volt range. The one-megohm resistor and 300-volt power source are the "keep alive" portion of the circuitry. (This feature was, however, found to be unnecessary with the high voltages used.) The KN-22 is triggered through a TR-130 trigger transformer (E G & G), either manually or by an adjustable cam programmer (Series 324C, Automatic Timing and Controls, Inc.). The number of discharges was monitored by a Durant Unisystem Counter Model No. 49600-403 which would shut off the cam programmer after a predetermined number of counts. As Figure 2 shows schematically, the trigger requirement is a 10-microfarad capacitor charged to 22.5 volts. The discharge spark energy is supplied by the 0.05 microfarad capacitor (Plastic Capacitors, Inc.). Measurements were made with a Tektronix Type 555 oscilloscope and a P6013A high voltage probe. The system rise time was 14 nanoseconds. For the tests on explosives, a 2.3-ohm resistor (R in Fig 2) was placed in series with the test item; this gives a relaxation time of 115 nanoseconds, which is well within the time resolution of the oscilloscope. To evaluate the experimental techniques and obtain a model of the discharge (See APPENDIX), resistances of 2.3, 4.7, 11, and 27 ohms were used in series. The energies delivered to the spark gap, the krytron, and the series resistors were determined from photographs of the current and voltage waveforms.

A sample prepared as described above was connected to the discharge circuit (with the center pin of the squib used as the positive electrode) and subjected to a series of discharges usually 1000 unless the item detonates before this number is reached. Composition B, tetryl, and lead azide were tested in this manner. All these tests were run using a 2.3-ohm series resistor.

To study the spark sensitivity of Comp B under high pressure, a stainless steel cylinder 3 3/4 inches long, 2½ inches in diameter, and ½ inch in wall thickness was fitted with a cap and an "o" ring. A high voltage was supplied to the interior by means of an electrical conductor sealing gland (Conax Corp., Type EGT-125-A-Cu). This vessel can maintain about 1500 psi for at least one hour with no noticeable drop in pressure. As a preliminary to the tests at high pressure, a squib was connected to the electrodes of the pressure bomb which was then pressurized with N_2 to 1350 psi. At a voltage of 3.4 kv and this pressure, no spark would break. The pressure was then slowly reduced until a discharge could be obtained. This did not occur until a pressure on the order of 25 psi was reached. Tests were therefore not run for ambient nitrogen pressures.

RESULTS

Capacitor Discharge

The distribution of energy in the series combination of test item, control resistor, and krytron switch during the capacitor discharges was determined by the procedure described below. The photographs of the voltage traces (See Fig 3 through 7) each represent a multiple exposure of about five discharges; this was necessary to obtain sufficient image intensity on the film being used.

The voltage across the spark gap of the test item when no explosive was present during discharge, is shown in Figure 3 for circuits employing each of the four series resistors that were used. Similar results were obtained with explosive present as Traces A in Figure 7 show. The horizontal time scale for all four photos in Figure 3 is 20 nanoseconds/division and the vertical scale is 1000 volts/division. Note that the recorded decay trace is the same for all four resistors. The capacitor voltage (3400 volts) bridges the spark gap until breakdown starts. In about 50 nanoseconds (as the spark forms), the voltage drops to the value appropriate to the spark resistance (a few hundred volts). This low value is maintained during the far longer balance of the capacitor discharge whose time constant is primarily due to other components in the circuit.

In Figure 4, the voltage is shown across the series combination of test item, spark gap, and control resistor. In A, the resistor is 2.3 ohms and the time scale is now 0.1 microsecond (100 nanoseconds) per division. Before spark formation, the voltage is 3400 volts. One sees first a region dominated by spark formation (about 50 nanoseconds). After spark formation, a period of decay (capacitor discharge) occurs lasting about 300 nanoseconds. As the value of the resistor is successively changed to 4.8, 11, and 27 ohms, one observes the classical lengthening of the discharge time. Note the changes in time scale in Figure 4.

In Figure 5, the voltage is shown for the resistor alone. Hence, the voltage starts from zero (representing no current) and increases until the spark forms. When the spark begins to form, the voltage rise is proportional to the current through the resistor. At the same time, the rise in current represents a drop in the voltage of the capacitor which is discharging. Hence, the peak voltage achieved is different for the four values of control resistor. Alternatively, one can understand this in terms of the smallest control resistor. This point is further considered in the APPENDIX. Again in Figure 5, one sees with different time scales the longer decay time obtained with the larger control resistors.

The voltage across the krytron and spark gap was studied using the modified circuit shown in Figure 2. The spark gap was included because, without it, the measurement instrumentation would introduce leakage adequate to fire the krytron. The result is shown in Figure 6 for the 11-ohm control resistor. Note that the voltage before breakdown was 3000 instead of 3400 volts. The difficulty here is that the probe input resistor, 100 megohms, is in series with the 10 megohm resistor of the charging circuit so that the capacitor is charged to a lower voltage because the voltage is divided between these two resistors. The voltage shown in Figure 6 represents the spark and krytron resistance as a function of time. It therefore shows a higher voltage at corresponding times than is shown in Figure 3 for the spark alone. The decay time seems slightly longer (possibly because the krytron characteristics change with use), but this difference is insignificant in relation to the longer capacitor discharge times.

Figure 7 shows a set of voltage traces for a test item containing Composition B. Comparison with previous traces, in which the test items used contained no explosives, shows that the phenomena are identical.

Energy Considerations

The voltage-time traces presented above can now be used to calculate the energy dissipated in the circuit elements. The control resistor trace provides a measure of the current common to all the series-connected circuit elements. The energy dissipated in a resistive circuit element is given by

$$E = \int_0^\infty V(t) I(t)$$

where V(t) is the voltage across and I(t) the current through the element. By dividing the time scale into sufficiently small segments, δt, and making use of Ohm's Law, this equation can be rewritten as:

$$E = \frac{\delta t}{R} \Sigma V(t) V_R(t)$$

where V_R (t) is the voltage across the resistor R. This expression was used to calculate the following energies:

E_R -energy dissipated in resistor ($V(t) = V_R(t)$ from Figure 5)

E_{G+R} -energy dissipated in spark gap and resistor (from Figure 4. Note that Figure 3 shows only spark formation.)

R (ohms)	E_R	E_{G+R}	$E_{G+R} - E_R$
2.3	0.150	0.177	0.027
4.8	0.175	0.191	0.016
11	0.172	0.205	0.033
27	0.232	0.254	0.022

The above data is of limited accuracy because of the difficulty of correctly including the energy of the low voltage tails in the graphical integration; also the resolution of the voltage from the photographs is only about $\pm$ 200 volts (due partly to the necessity of multiple exposures). Further, the values for the gap energy ($E_{G+R} - E_R$) suffer from the inherent uncertainty of a small difference between two much larger numbers. However, it is only used here to show that about 10% of the total stored capacitor energy is dissipated in the spark gap and is therefore potentially available to cause explosive initiation. Hence, for the tests on initiation of explosives conducted with the 2.3 ohm control resistor, it is considered that sparks of energy of about 0.03 joules (300,000 ergs) were applied with a time constant of about 0.2 microsecond. The traces to which these energy/time characteristics apply are shown in Figure 7.

In all, about 60-90% of the total stored energy could be accounted for depending on the size of the series resistance. The major portion of the energy is dissipated in the added resistor. A residual energy in the capacitor results because, as the voltage across the krytron and the gap drops below the sustaining voltage, the discharge stops. A more complete discussion of this point is given in the APPENDIX. In the last column above, any dependence on the size of the resistor of the total energy expended in the spark is less than the uncertainty of the experimental determination.

<u>Explosive Test Data</u>

The results of tests conducted at ambient gas pressures are summarized in Table 1. The loading pressure used was 1300 psi because, at higher pressures, reproducible sparks could not be formed. Items loaded with Comp B at loading pressures of 14000 and 7000 psi did not allow a spark to break up to 4000 volts, the highest voltage tried.

Items loaded in the range of 1700-2800 psi loading pressure tended to delay spark formation for a few seconds to a few minutes. At the 1300 psi loading pressure used in the test, the spark formed without any problem. All the tests were carried out in air at atmospheric pressure using 3400 volts. In the case of lead azide, all of seven items tested were initiated by the first spark applied to each item. For both tetryl (5 items tested) and Composition B (20 items tested), no initiation occurred even where 1000 successive sparks were applied to each item. However, when individual items containing these explosives were opened after testing, considerable decomposition of the material where it came into contact with the squib surface was found. In some cases, this decomposition extended to a depth of approximately 1 mm. The evolution of gaseous products from this decomposition caused a slight swelling in the side wall of the aluminum detonator cup.

No tests were run at high pressure because no spark could be made to break at an ambient pressure only 25 psi above atmospheric.

DISCUSSION

Simulation

This work was directed toward the simulation of one possible cause of the premature detonation of a shell. However, the exact circumstances under which Composition B would be subjected to spark energy could not be fully defined. Ordinarily, an insulated wire passes in the vicinity of a metal fuze housing and this wire is not "live" in the electrical sense. However, if particular defects exist then the wire may become "live" during the launching of the shell. If so, the wire may be considered as connected to a 1500-picofarad capacitor charged to up to 3000 volts. This represents 0.00675 joules.

The conditions under which a spark may occur require further defects. The insulation must be damaged. There may be a small gap to the metal fuze housing. There may be a small exposed gap in the wire itself. In this work, only the fixed small gap cases have been simulated. The initial contact possibility for this munition has been studied by another investigator (Boyd C. Taylor, BRL).

The condition of the explosive that comes into contact with the spark was assumed to be cast material which had been locally worked to form a powder. The maximum setback pressure was about 14000 psi. However, pockets could exist within the cast material particularly near surfaces close by the fuze housing so that powder would not be re-pressed by setback pressures. Further, the gas pressure within the powder and surrounding available spaces may be increased by the deformation of the explosive under setback, but not necessarily to the full setback pressure. (For example, the space under an arch of a heavily loaded bridge is at atmospheric pressure.) As reported herein, the simulation consisted fo crushed cast Composition B re-pressed to 1300 psi which was found to be the highest loading pressure for which a reproducible spark would form at atmospheric pressure. Increasing the ambient pressure above about 25 psi prevented the formation of a spark at this (1300 psi) loading pressure. For higher ambient pressures, one could generate a spark (for the voltages involved) only by using the contact mechanism initially studied at BRL. The 1300 psi loading pressure provided a porous matrix of crushed Composition B in intimate contact with the electrodes. Since the explosive is a thermal insulator, no heat loss as compared to loose powder is introduced by the pressing. The spark gap length chosen, 0.03 inches, provided a reproducible spark for the available voltage and was generally comparable to the length of gap that might lead to a spark in the munition.

If the spark resistance was 0.1 ohm, then the discharge of a 1500-picofarad capacitor would have a time constant of 0.15 nanoseconds. Providing a reproducible spark with so short a decay and making measurements of its performance posed severe equipment problems. It was therefore decided to provide a somewhat larger spark energy, but with a slower decay. The method has been fully explained in previous sections of this report. Note that the initial breakdown across the spark gap still occurs in a few nanoseconds (Fig 3); hence, the available energy or heating in the simulation has a fast onset but lasts longer than in the munition. The simulation conditions are considered much more severe than those that could occur in the munition. Yet, no initiation occurred for Composition B. The results with tetryl indicate that the mechanism is quite unlikely to cause initiation in an explosive that is somewhat more sensitive than Comp B (Ref 2). The lead azide tests were run to demonstrate that the apparatus is capable of initiating a sensitive explosive.

Test Item

The electrode assembly most commonly used in spark-sensitivity testing is a metal needle and metal plane; very often the upper electrode is moving. (See Reference 3 for a survey of electrostatic sensitivity test methods.) The sample powder is placed in a pile in line with the moving electrode. When high voltages are used, the sample is surrounded by a nonconductive material to prevent the discharge from bypassing the explosive.

The present work used a somewhat different arrangement in which the two electrodes are in the same plane and a spark was made to break across the surface of an explosive in contact with the electrodes. It was felt that this setup would give a more definite and reproducible configuration of spark gap and explosives and be more amenable to the multiple test procedure than the moving electrode assembly. With the latter, the explosive material would be disturbed not only by the discharge, the effect of which is discussed in the next section, but also by the penetration of the needle with unknown effects.

It was necessary to make the glass spacer longer than the outer metal ring to increase the length of any possible breakdown path at the back surface of the squib. Preliminary work with a squib of slightly smaller dimensions and not having the extended spacer resulted in breakdown across the rear surface of the squib, when a voltage was applied while the front surface was in intimate contact with an explosive.

Multiple Tests

A premature in-bore accident is a rare occurrence. Different, unsubstantiated hypotheses have been advanced as causes for consideration. The electrostatic discharge mechansim is one such hypothesis. It requires the coincidence of several unlikely events to even generate a spark. In the simulation, the existence of each spark must therefore itself be regarded as a low probability event. Yet, if one wanted to assign a number to the probability one would have to test the effect of many sparks, perhaps millions, on the explosive to obtain data suitable for statistical treatment. The cost involved (in materials and time) bars such tests. However, one simplification now to be discussed can increase the number of tests at low cost. This is to subject a single sample to many sparks. The problem here is to define the change induced by prior sparks. Samples subjected to various numbers of sparks were disassembled. It was concluded that decomposition without initiation was occuring. At first, no evidence of change could be visually observed. As the number of sparks increases, gas would be evolved, and discoloration of the surface near the spark would occur. A ratio of 1000 sparks per test item was chosen as the useful life of a sample. It is believed that decomposition by a spark without initiation is in itself a test of the initiability of the material, albeit not of exactly the same material as for the first spark. Further exploration of the effects of multiple spark testing would be needed before this technique could be adopted as a standard procedure.

Conclusions

The multiple tests reported in the results (20 items, 1000 sparks each) were preceded by a variety of tests of many samples with other configurations of test item and other circuit arrangements. In all cases, no initiation occurred. As a rough summary, one could conservatively say that 50 samples were subjected collectively to perhaps 50,000 sparks and yielded not a single initiation. The probability of spark initiation by the fixed gap mechanism is considered so small that it is believed that seeking further experimental data to determine a numerical value is not worthwhile. Instead, emphasis should be directed toward other mechanisms, and quality control should be used to eliminate the possibility of any electrostatic mechanism.

FURTHER WORK

The conclusions of the previous section indicate that further work on the particular premature mechanism involved here would not prove fruitful. However, this investigation has suggested several areas in need of additional study. For example, faster instrumentation would allow the investigation of shorter discharge periods; hence, the range could be extended beyond the values used in this special case. Improved instrumentation would also permit better voltage estimates to be made from the photographs; this is necessary for a more precise energy determination. As a check on the procedure used here, an alternate method should be employed to determine the energy in the spark gap; e.g., calculating the energy input by examining the shock wave set up by the spark.

The role of pressure and ambient gases (N_2, H_2O, O_2...) should be examined. In order to study effects at high pressure, one would have to go to increased voltages or a smaller gap length; this follows from Paschen's Law (Ref 4) which states that the sparking potential is a function of the pressure-gap length product. With regard to pressure effects, the relationships of the results reported herein to those obtained by investigators at BRL are worth further study. The people at BRL have reported initiation by the initial contact method in the presence of ambient nitrogen pressures of about 1900 psi.

As has been pointed out in the DISCUSSION section of this report, some of the explosive in contact with the electrode in items that had been subjected to a number of discharges was found to be decomposed. Therefore, the technique of multiple discharges on a single item must be studied with a view to determining just how many discharges can be applied and still have some of the original explosive in contact with the electrode. The changes in the surface of the explosive under successive sparks could be monitored with the scanning electron microscope. However, one must recognize the fact that changes in, for example, submicroscopic electronic structure, charge distribution or nature and quantity of entrapped decomposition gases, any of which would be undetectable by the electron microscope, could occur. It is not obvious, a priori, whether such changes would make the sample more or less sensitive to spark initiation.

The time to initiation as a function of energy or mean power should be investigated since the rate of application of a given amount of energy is a most important factor influencing the ignitability of an explosive.

The distribution of the energy that is dissipated in the spark gap is also in need of investigation. Complex energy transfer problems exist here; for example, some of the energy released in the gap goes into heating the electrodes. High-speed photographic techniques can be used to examine processes occurring at the surface of the electrodes. Experiments of the preceding type should produce information useful not only for an understanding of the fundamental processes involved in spark initiation but also for development of a reliable standardized spark sensitivity test.

ACKNOWLEDGMENT

The author wishes to thank Mr. J. Hershkowitz, Chief, Applied Physics Branch, for his valuable assistance at various stages of this work and his suggestion of the multiple-test-per-item procedure. Special thanks are due to Dr. C. R. Westgate for his assistance in solving electrical measurement problems and for the mathematical model appearing in the APPENDIX.

REFERENCES

1. T. P. Liddiard, Jr., "The Characteristics of Electric Spark Discharges in Mixtures of High Explosive and Aluminum Powders", NOLTR 61-67, 25 August 1961

2. Henry J. Jackson, "A Study of the Electrical Characteristics of Some Explosives and Explosive Mixtures", PATM 1288, Picatinny Arsenal, October 1963

3. William E. Perkins, "A Survey of the Methods of Testing The Electrostatic Sensitivity of Solids", Memorandum Report M69-29-1, December 1969

4. Leonard B. Loeb, "Fundamental Processes of Electrical Discharge in Gases", John Wiley & Sons, pp. 410-415 (1939)

5. Reference 4 pp. 441-448

6. P. W. J. Moore, J. F. Sumner and R. M. H. Wyatt, "The Electrostatic Spark Sensitiveness of Initiators: Part 1: Introduction and the Study of Spark Characteristics", E.R.D.E. 4/4/56, 10 January 1956

TABLE 1

Explosive Test Data

Explosive	Comp B	Tetryl	PbN_6
Weight, mg	55	75	80
Loading pressure, psi	1300	1300	1300
Ambient gas pressure	air/atmos	air/atmos	air/atmos
Voltage	3400	3400	3400
Items tested	20	5	7
Discharges per item	1000	1000	1
Number fired	0	0	7

TABLE 2

Calculated energy dissipation and time to maximum current as functions of control resistor

R(ohms)	t_{max}^{calc}	t_{max}^{expl}	E_R	E_{K+G}	E_I
2.3	57	100	0.200	0.0877	0.0577
4.8	74	110	0.226	0.062	0.030
11	97	120	0.242	0.046	0.014
27	123	140	0.250	0.038	0.006

t in nanoseconds
E in joules

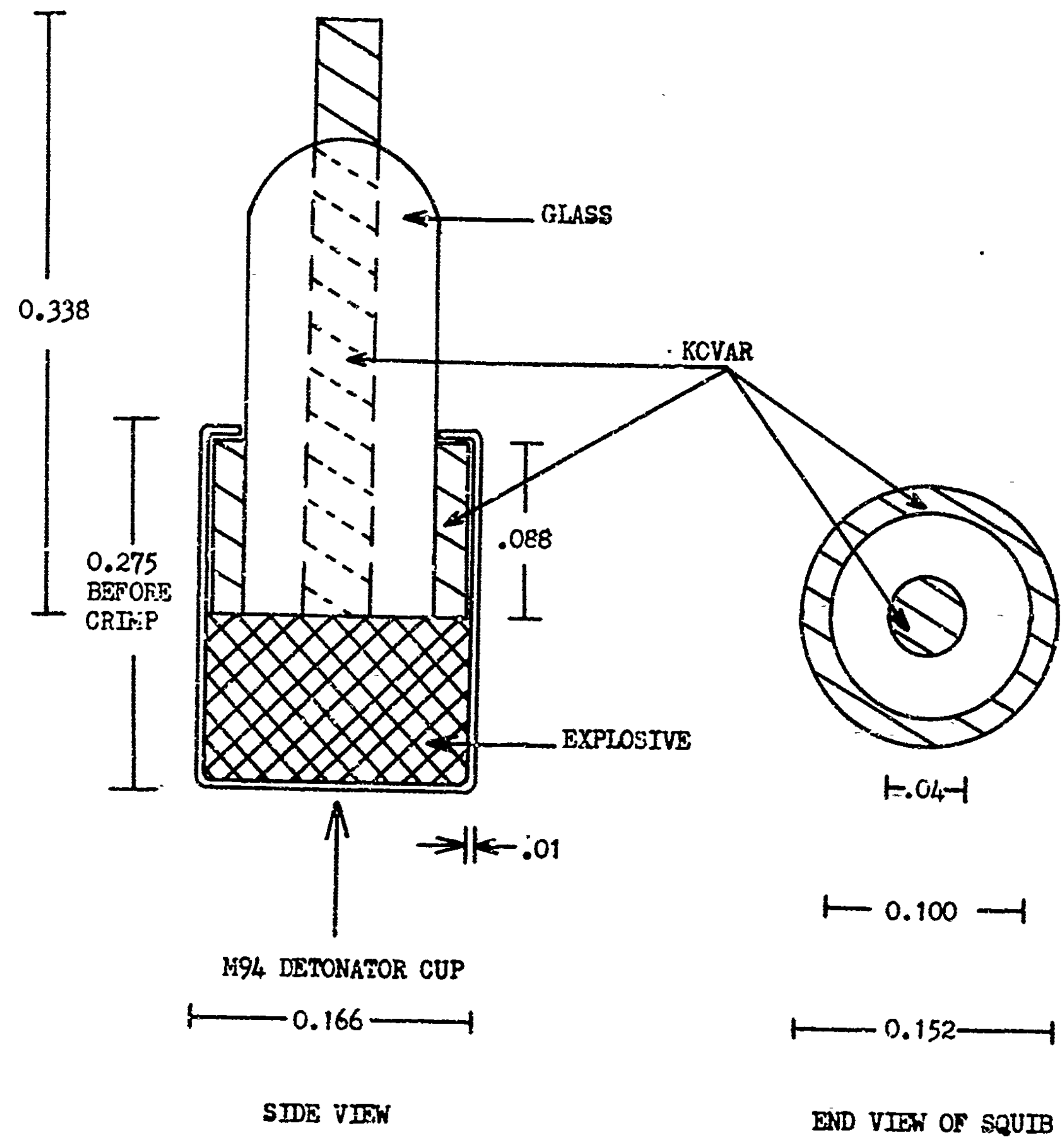


Fig 1 Detonator/squib assembly

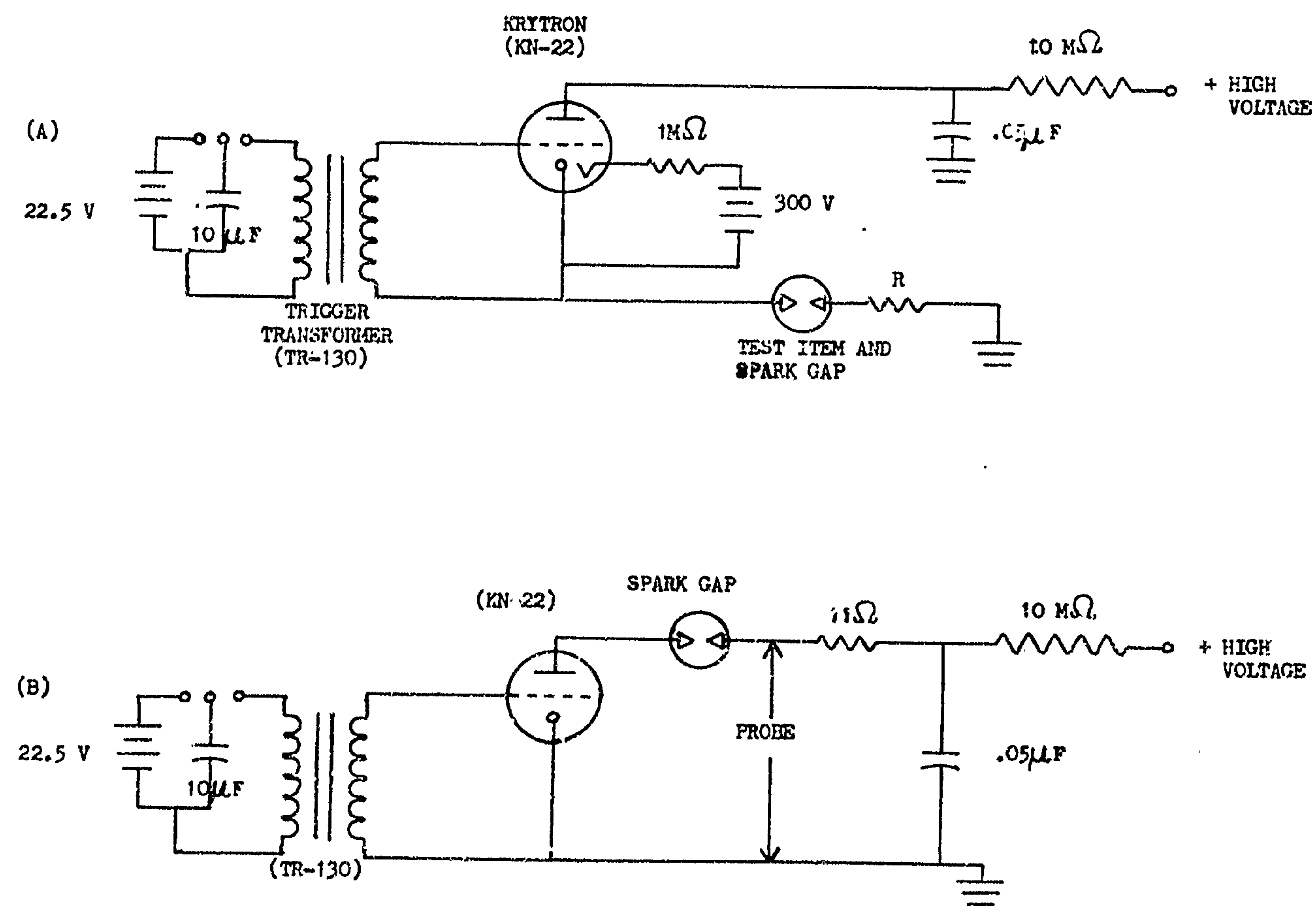
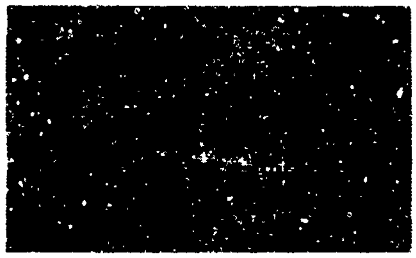
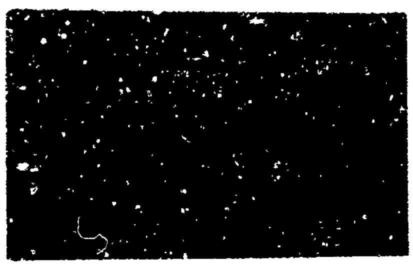


Fig 2 Circuits used

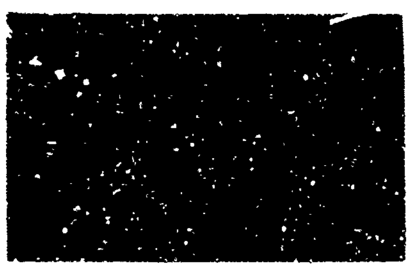


(A) 2.3 OHMS

(B) 4.8 OHMS

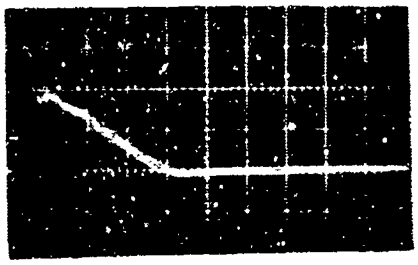


(C) 11 OHMS

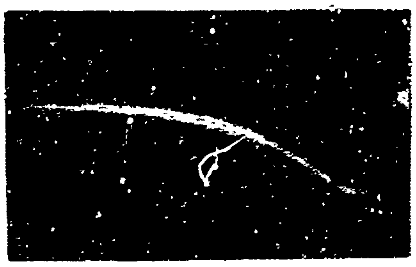


(D) 27 OHMS

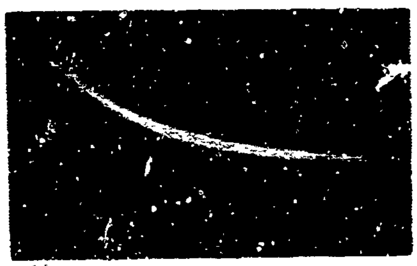
Fig 3 Voltage across spark gap during discharge. Vertical scale: 1000 volts/division. Horizontal scale: 20 NSEC/division



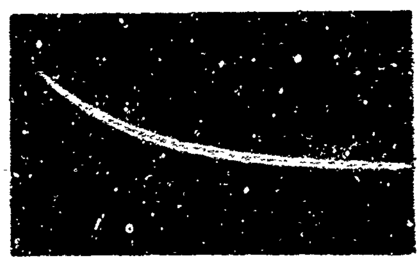
(A) 2.3 OHMS; 0.1 μ SEC/DIVISION



(B) 4.8 OHMS; 0.1 μ SEC/DIVISION



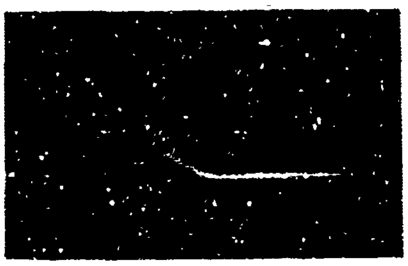
(C) 11 OHMS; 0.2 μ SEC/DIVISION



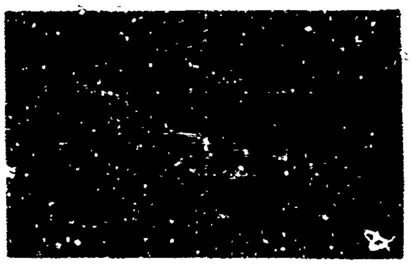
(D) 27 OHMS; 0.5 μ SEC/DIVISION

Fig 4 Voltage across spark gap and resistor during discharge. Vertical scale: 1000 volts/division

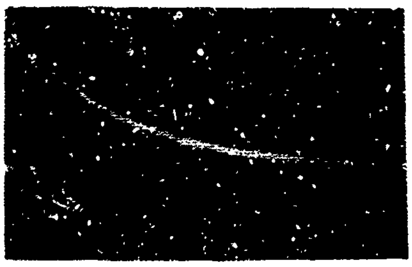
NOT REPRODUCIBLE



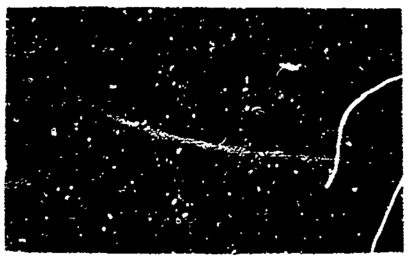
(A) 2.3 OHMS; 0.1 μ SEC/DIVISION



(B) 4.8 OHMS; 0.1 μ SEC/DIVISION



(C) 11 OHMS; 0.2 μ SEC/DIVISION



(D) 27 OHMS; 0.5 μ SEC/DIVISION

Fig 5 Voltage across resistor during discharge. Vertical scale: 1000 volts/division

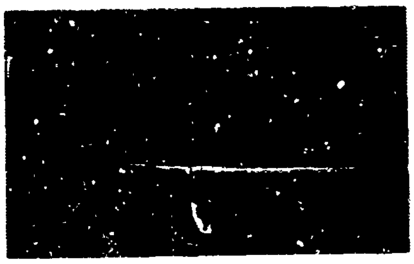
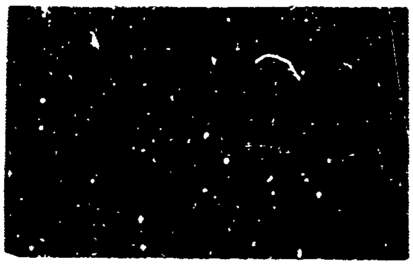


Fig 6 Voltage across krytron and spark gap during discharge. Vertical scale: 1000 volts/division Horizontal scale: 40 NSEC/division

NOT REPRODUCIBLE



(A) VOLTAGE ACROSS ITEM (I. E. SPARK GAP); 20 NSEC/DIVISION

(B) VOLTAGE ACROSS ITEM AND 2.3 OHM RESISTOR; 0.1 μ SEC/DIVISION

(C) VOLTAGE ACROSS 2.3 OHM RESISTOR; 0.1 μ SEC/DIVISION

Fig 7 Typical voltage traces for a Comp B loaded item. Vertical scale: 1000 volts/division

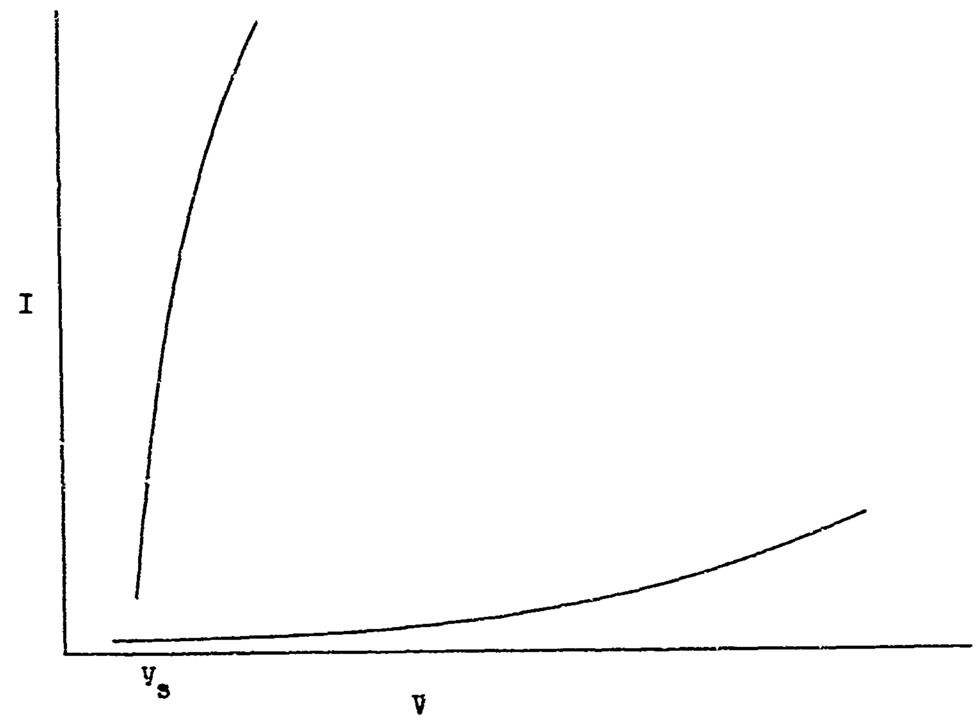


Fig 8 Current-voltage characteristic of a spark gap

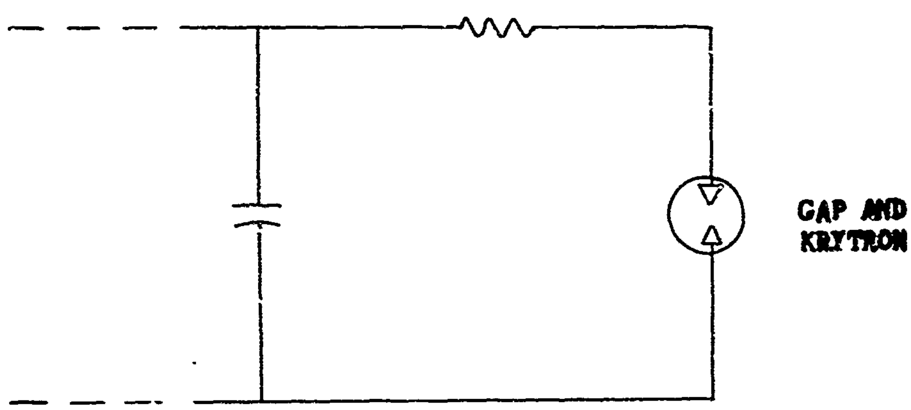


Fig 9 Schematic of discharge circuit

APPENDIX

MATHEMATICAL MODEL OF THE DISCHARGE CIRCUIT

The purpose of this APPENDIX is to present a model for the discharge of the capacitor through the spark gap, the series resistance, and the krytron. Since the dynamics of the breakdown of a spark gap are not well understood, it is necessary to make some simplifying assumptions. The current-voltage characteristics of the spark gap are those of a current-controlled negative differential resistance. The static characteristic is shown in Figure 8. The trajectory of the current is determined by the series resistance and the dynamics of the energy accumulation process during initiation of the spark. The latter is a function of the details of the gap geometry and the ambient and is the least understood process operating in the discharge.

Experimentally, it was observed that the voltage across the spark gap during breakdown is independent of the series resistance; this is also assumed to apply to the krytron. Motivated by Figure 6, we approximate the voltage across both by

$$V_{G+K} = (V_o - V_s)\, e^{-t/\tau} + V_s \qquad \text{(A1)}$$

where V_o is the initial voltage from the power supply, V_s the sustaining voltage below which the discharge will cease due to gap or krytron ceasing to pass current and τ is a time constant. The time is measured from the initial decrease in voltage across the gap. A delay time is observed in most cases. As discussed by Loeb[5], this delay is purely statistical in time. Since no current flows during the delay time, no energy is dissipated in the circuit.

Because, with the control resistors used, the RC time constants were larger than 100 nanoseconds, the effects of parasitics such as the inductances in the wires were negligible and the discharge circuit can be represented by the lumped components shown in Figure 9. From Kirchoff's voltage law, we have

$$V_{G+K} + V_R = V_o \qquad \text{(A2)}$$

Substituting from equation A1 and rearranging yields

$$R\frac{dQ}{dt} + \frac{Q}{C} = (V_o - V_s)\ e^{-t/\tau} + V_s \qquad \text{(A3)}$$

where Q is the charge on the capacitor at time t and I = -dQ/dt. The solution to the homogeneous equation is

$$Q = Ae^{-t/RC} \qquad \text{(A4)}$$

The particular solution can be found by assuming

$$Qpart = K_1 + K_2\ e^{-t/\tau} \qquad \text{(A5)}$$

and substituting into equation A3 to give

$$-\frac{RK_2}{\tau}\ e^{-t/\tau} + \frac{K_1}{C} + \frac{K_2\ e^{-t/\tau}}{C} = (V_o - V_s)e^{-t/\tau} + V_s$$

Equating coefficients of like terms, we find

$$K_1 = CV_s$$

$$K_2 = \frac{C\tau(V_o - V_s)}{\tau - RC}$$

so that the solution of A3 is

$$Q = Ae^{-t/RC} + CV_s + \frac{C(V_o - V_s)\tau e^{-t/\tau}}{\tau - RC} \qquad \text{(A6)}$$

From the initial conditions that at t = 0, $Q = Q_o = CV_o$, A is found to be

$$A = \frac{-RC^2\ (V_o - V_s)}{\tau - RC}$$

The current in a circuit element is given by

$$I = \frac{dq}{dt} = \frac{d}{dt}(Q_o - Q) = -\frac{dQ}{dt}$$

so that

$$I = \frac{-dQ}{dt} = \frac{C(V_o - V_s)}{RC - \tau}\left(e^{-t/RC} - e^{-t/\tau}\right) \quad \text{(A7)}$$

The energy in the gap and krytron is given by

$$E_{G+K} = \int_0^\infty V_{G+K} I dt \quad \text{(A8)}$$

Substituting the expressions for V_{G+K} and I from A1 and A8 and integrating gives

$$E_{G+K} = CV_s (V_o - V_s) + \frac{C(V_o - V_s)^2 \tau}{2(RC + \tau)} \quad \text{(A9)}$$

Similarly, the energy dissipated in the resistor

$$E_R = \int_0^\infty V_R I dt = \int_0^\infty I^2 R dt$$

is

$$E_R = \frac{C(V_o - V_s)^2}{2} \frac{RC}{RC+\tau} \quad \text{(A10)}$$

The sum of equations A9 and A10 is

$$E_{G+K} + E_R = \frac{C}{2}(V_o^2 - V_s^2).$$

This is the energy expended in the gap + Krytron + resistor; it is the initial energy in the capacitor minus the energy left in the capacitor after discharge. $CV_s^2/2$ is the energy left in the capacitor: when the voltage drops below V_s, no more breakdown occurs.

At this point, it will be instructive to compare some predictions of the model with experimental findings. In Table 2, we list calculated values for E_R, E_{G+K}, and t_{max}; and the time to reach maximum current along with the experimental value t_{max}. For all the calculations, the value of τ, approximated from Figure 6, was taken as 32 nanoseconds, while V_s was estimated to be about 200 volts. The time to maximum current is found by setting the time derivative of equation A7 equal to zero and solving for t. Thus we have

$$t_{max} = \frac{\tau RC}{RC-\tau} \ln \left(\frac{RC}{\tau}\right) \qquad \text{(A11)}$$

From the second and third columns of Table 2, it is apparent that there is at least qualitative agreement between calculated and experimental times; this agreement becomes better with increasing value of the control resistor. The experimental values were obtained from pictures similar to those of Figure 5, but run at slower sweep rates (0.5 microsecond/div) so that there would be a sharper peak.

For a sufficiently large resistor, it is obvious from equations A9 and A10 that both E_{G+K} and E_R are independent of the control resistor. This implies that the energy in the spark gap is also independent of the control resistor-a fact in agreement with the results reported by Moore, et. al. (Ref 6), who found that a reasonably constant value of about 10% of the stored energy appears in the spark gap when resistors of 10^3 to 10^7 ohms were placed in series.

As Figure 5 shows, the magnitude of the voltage across the resistor does not reach the applied voltage (3400 volts); this is particularly evident for the smaller resistors. The following arguments offer some insight into this behavior. In the first place, the spark gap and krytron both have resistances which are in series with each other and with that of the control resistor. Hence, when the voltage across the control resistor is measured, there is a voltage divider effect, which tends to reduce the measured voltage. Since the overall resistance of gap krytron after breakdown is at most of the order of a few ohms, i.e., comparable in magnitude to the smaller resistances, the reduction is greater for the smaller control resistors. This voltage divider effect could be corrected for if one knew the time dependences of the resistances of the spark gap and of the krytron. Unfortunately, we do not know the individual values for these resistors, and a crude attempt to determine their combined value gave varying results depending on the control resistor used. A further complication is the fact that the voltage divider effect is not the only factor affecting the peak voltage. As has been mentioned in the RESULTS section of this report, the discharge rate also affects the peak voltage achieved. With a zero or small resistance in the discharge circuit, the current initially builds up to a very high value since there is little resistance to limit it. A good deal of the energy stored in the capacitor goes into initiating the breakdown and by the time the spark is fully developed very little energy is left and therefore little voltage results across the resistor. On the other hand, a large resistor keeps the initial current down and slows down the discharge so that most of the energy gets into the gap after initiation.

Equation A9 lends some support to the above argument if we associate the second term on the right hand side with the energy necessary to initiate the spark, i.e., both the spark gap and the krytron. Values for this term are listed in the last column of Table 2, headed E_I - the initiation energy. We see that, as the value of the control resistor increases, the energy expended in initiating the spark decreases; therefore more energy gets into the later stages of the discharge.

The first term on the right-hand side of equation A9 is a measure of the energy spent in both the spark gap and the krytron after initiation. It is independent of resistance and, for the experimental quantities used in this work, amounts to some 0.032 joule. The experimentally determined spark gap energies ($E_{G+R}-E_R$, page 8) are calculated from quantities that were measured over time durations that were long when compared to those involved in spark initiation and therefore should not be too much influenced by the initiation energy. These results are seen to be in at least qualitative agreement with the value of 0.032 joule for the first term of equation A9. It must be emphasized that the measured energies are for the spark gap alone while the calculated energy contains a contribution from the krytron. For the present model, it is not possible to separate gap energy from that of the krytron. However, one possible interpretation of these results is that most of the available energy (0.032 joule) is expended in the spark gap and very little in the krytron.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D			
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)			
1. ORIGINATING ACTIVITY (Corporate author) Picatinny Arsenal, Dover, N.J. 07801		2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP	
3. REPORT TITLE AN ELECTROSTATIC SPARK SENSITIVITY TEST OF COMPOSITION B			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
5. AUTHOR(S) (First name, middle initial, last name) Robert F. Gentner			
6. REPORT DATE December 1970		7a. TOTAL NO. OF PAGES 34	7b. NO. OF REFS 6
8a. CONTRACT OR GRANT NO. b. PROJECT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 4119	
c. AMCMS CODE: 4810.16.2929.6 d.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	

13. ABSTRACT

This report describes an investigation related to the possibility that an accidental electrostatic discharge within a munition may initiate a Composition B main charge. The source, in the supposed mechanism, is a 1500-picofarad capacitor charged to a maximum of 3000 volts (67,500 ergs). The fraction of this energy available to the explosive, as a function of time depends on the circuit parameters and the arc characteristics. The test device used to simulate the discharge stress applied to the explosive employed a 0.05microfarad capacitor charged to 3400 volts. Approximately 10% (300,000 ergs) of the stored energy appears in the spark gap with about a 0.2-microsecond time constant for the discharge. Repeated application of this discharge to the surface of the explosive did not initiate the Composition B. A method for measuring the energy in the spark gap is described. A mathematical model of the discharge circuit is developed and its predictions are compared with the experimental results. The potential of the test device for measuring the electrostatic sensitivity of explosives is discussed.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrostatic spark sensitivity of Explosives						
Composition B						
Discharge circuit						
Energy dissipation						
Maximum current						
Control resistor						
XM409 shell, premature detonation						
Concentric electrodes						
Multiple spark testing						
KN22 Krytron (EG&G)						
TR-130 trigger transformer						
Current and voltage waveforms						
Electrical conductor sealing gland						
Ohm's law						
Gas pressures						
Configuration of test item						
Paschin's law						

UNCLASSIFIED
Security Classification